INFLUENCE OF LOADING RATE ON FATIGUE CRACK GROWTH RATE

K. Golos, Z.Osiński*

The effect of loading rate on the fatigue crack growth at low and intermediate ΔK values is investigated. In the analysis a singularity field modified from Rice's solution for anti plane shear to calculate local stress and strain is adopted. A simplified crack growth equation is derived involving mechanical, cyclic, fatigue properties as well as a length parameter, describing damage zone associated with microstructure.

INTRODUCTION

The fatigue crack growth rate (FCGR) may be influenced by many factors associated with load history and environment. In the present paper the effect of the frequency of loading on FCGR is analyzed. Experimental data suggest that FCGR can be expressed by modified Paris relation proposed by Yokobori and Sato (1)

$$da/dN = A\ (\Delta K)^{m} f^{-\lambda} \tag{1}$$

where ΔK is stress intensity range, f is frequency and A, m and λ (λ>0) are material parameters. It is worth to mention that this parameters are generally determined experimentally.

It is objective of this paper to examine and propose a crack propagation model with the effect of loading rate.

* Warsaw Technical University, ul.Narbutta 84, 02-524 Warsaw, Poland.

CRACK GROWTH DESCRIPTION

It has been widely recognized (Antolovich (2); Radon (3); Golos (4), (5)) that a small region defined as a damage zone exists immediately adjacent to the crack tip. This zone can be defined as the set of grains that has reached the state of fatigue damage. Fatigue damage leads to failure when the level of strain energy density in the damage zone reaches a critical value. Therefore to estimate this process, failure criterion as well as stress and strain distribution ahead of the crack tip has to be known. As the general equation for stress/strain field ahead of the fatigue crack are not known, approximations are made from the stationary solutions as suggested by Rice (6). In the present analysis the strain energy density ahead of the crack tip is considered. Therefore, fatigue criterion based on the plastic strain energy density failure criterion is used.

Since the fatigue damage is generally caused by the cyclic plastic strain, the plastic strain energy plays an important role in the damage process. Therefore, the plastic strain energy density has been proposed as a damage parameter for low cycle fatigue (Golos (7)). Then the plastic strain energy fatigue failure criterion can be expressed in general form as:

$$\Delta W^{p}=\zeta(2N_{f})^{\alpha}f^{\beta} \tag{2}$$

where the values of ζ , α and β are materials parameters. In the case when the values of ζ , α and β are not available, the approximated relationships can be compute based on "frequency-modified" Manson-Coffin (8) equation , i.e.

$$\alpha \cong b + c \quad ; \zeta \cong 4\sigma'_{f}\varepsilon'_{f}\frac{1 - n'}{1 + n'} \quad ; \beta \cong d+e \tag{3}$$

where n' is the cyclic strain-hardening exponent, (σ'_{f}/E) and ε'_{f} are the strain amplitudes corresponding to the elastic and plastic intercept for one cycle, b is the fatigue strength exponent, c is the fatigue ductility exponent, d and e are material constants.

Based on Rice (6) analysis of a stationary crack in anti plane shear under small scale yielding and

McClintock (9) discussion on the analogy between mode III and mode I stress and strain distribution near crack tip can be approximated by:

$$\Delta\sigma\ (x) = \sigma_y' \left[\frac{\Delta K^2}{(1 + n')\pi(\sigma_y')^2 (x + r_c)} \right]^{n'/1+n'} \qquad (4.a)$$

$$\Delta\varepsilon\ (x) = \varepsilon_y' \left[\frac{\Delta K^2}{(1 + n')\pi(\sigma_y')^2 (x + r_c)} \right]^{1/1+n'} \qquad (4.b)$$

where ΔK is the stress intensity range, σ_y' is cyclic yield stress, ε_y' is the cyclic yield strain, n' is the cyclic strain hardening exponent.

Therefore, the plastic strain energy distribution ahead of the crack tip can be expressed as follows:

$$\Delta W^p = \frac{(1 - n')}{(1 + n')^2 \pi (x + r_c) E} \Delta K^2 \qquad (5)$$

Analysis of the fatigue crack growth during cyclic loading requires a fatigue failure criterion and specification of the zone where such a criterion can be applied. The finite element calculations of stress and strain ahead of the crack tip have shown, that there exists a small region - damage process zone, denoted herein by δ.
The number of cycles, ΔN to penetrate damage zone, i.e. a crack growth of δ, can be determined from eqn.(2)

$$2\Delta N = (\Delta W^p / \zeta f^{\beta})^{1/\alpha} \qquad (6)$$

The plastic strain energy density within the process zone may be calculated from equation (5) setting by $x=\delta$.

$$\Delta W^{p} = \frac{(1 - n')}{(1 + n')^{2}\pi(\delta + r_{c})E}\Delta K^{2} \qquad (7)$$

Substituting from equation (7) into (6) the crack growth rate per cycle, da/dN is therefore can be estimated as follows:

$$\frac{da}{dN} = \frac{\delta}{\Delta N} = \frac{\Delta K^{2}}{\zeta\frac{(1+n')^{2}}{(1-n')}\pi E f^{\beta}} \frac{2\Delta N^{-\alpha}}{\Delta N} - \frac{r_{c}}{\Delta N} \qquad (8)$$

The r_c can be calculated, assuming that for $\Delta K = \Delta K_{th}$, $da/dN=0$.
Rearranging equation (8), the FCGR can be described as:

$$\frac{da}{dN} = 2\delta \left[\frac{\Delta K^{2} - \Delta K_{th}^{2}}{\zeta \frac{(1+n')^{2}}{1-n'} \pi E \delta f^{\beta}} \right]^{-1/\alpha} \qquad (9)$$

COMPARISON WITH EXPERIMENT AND DISCUSSION

In the analysis the values of ζ, α and β were calculated from equation (9). Therefore, the relationship for predicting the FCGR can be expressed in the form

$$\frac{da}{dN} = 2\delta \left[\frac{\Delta K^{2} - (\Delta K_{th})^{2}}{4\sigma_f' \varepsilon_f' (1+n') E \delta f^{d+e}} \right]^{-1/b+c} \qquad (10)$$

In the analysis experimental data for SM 50 steel (1) have been used.
The experimental and theoretical results for that material are shown in Fig.1. As has been shown , the predictions of the crack growth rates using the present model give good results, at least for the material considered.
The model developed herein indicates that constants in the Yokobori-Sato empirical equations are mutually dependent.

REFERENCES

(1) Yokobori, T. and Sato, K., Eng. Fracture Mechanics, Vol.8, 1976, pp.81-88.

(2) Antolovich, S.D., Saxena A. and Chanani, G.R., Engng. Fract. Mech., Vol.7, 1975, pp.649-652.

(3) Radon, J.C., Int.J. Fatigue, Vol.4, 1982, pp.161-166.

(4) Golos, K., Mechanical Behaviour of Metals (ICM 5), Ed.M.G.Yan, Pergamon Press, 1987, Vol.I, pp.567-573.

(5) Golos, K., Archiwum Budowy Maszyn, 1988, Vol.XXXV, pp.109-119.

(6) Rice, J.R., Transaction ASME, J. Applied . Mech., 1967, Vol.34, pp.287-298.

(7) Golos, K. Arch. Bud. Maszyn, Vol.35, 1988, No 1-2, pp.5-16.

(8) Coffin, L.F.,Metallurgical Trans., 1971, 12, pp.3105-13.

(9) McClintock, F.A., in FRACTURE, Ed. H.Leibowitz, New York, Academic Press, 1971, Vol.III, 48-227.

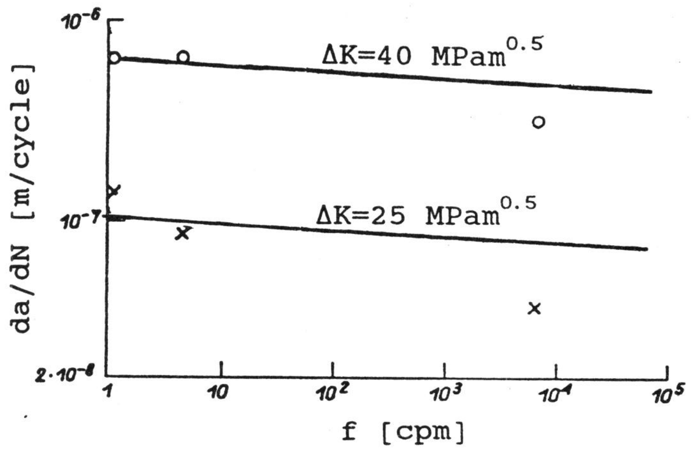

Figure 1 Relationship between experimental and calculated values of FCGR as a function of frequency.